Teaching Portfolio

Tyler McMaken

Ph.D. Candidate, Physics

In fulfilment of the requirements for the

Certificate in College Teaching

—

Department of Physics

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—

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I. INTRODUCTION

I have created this teaching portfolio with two goals in mind:

1. The document serves as a required final component in the process of obtaining the Certificate in College Teaching (CCT), sponsored by the Center for Teaching & Learning (CTL) in collaboration with the Graduate School at the University of Colorado Boulder (CU Boulder).
2. The document serves as a record (for future reference by myself and/or others working in higher education) of all the skills, experiences, and lessons I have learned during a critical period of education in my life while working towards a PhD in Physics and serving almost every semester as either a Teaching Assistant (TA) or full instructor.

The full list of classes I taught during my time in graduate school can be found near the end of my Curriculum Vitae (CV) in Sec. V. The experiences from these courses, along with frequent interactions with members of CU Boulder's Physics Education Research group and events sponsored by the CTL, have helped improve my teaching immensely and have further fueled my passion for teaching in the context of higher education.

The structure of this document will proceed as follows: in the remainder of this Introduction (Sec. I), I will detail the specific requirements of the CCT and will describe my experiences attending workshops and fulfilling the other requirements of the certificate. Then, I will provide a statement of my current teaching philosophy (Sec. II) based on my past and current experiences. Next, I will describe my assessment practices (Sec. III), including both *formative assessments* on my teaching (which do not count toward students' grades) and *summative assessments* on the students' performance (such as homework assignments and exams). Then, I will provide a statement of my philosophy and contributions toward diversity in education (Sec. IV), and finally, I will provide a complete copy of my current CV (Sec. V). The document will then conclude with a set of Appendices containing supplemental information compiled throughout my time at CU Boulder.

The CCT is sponsored by CU Boulder's Center for Teaching & Learning (formerly the Graduate Teacher Program when I first arrived at CU Boulder). The certificate requires that I complete the following tasks:

- Attending 20 workshops offered by the CTL or approved collaborators.
- Completing at least 20 hours of discipline-specific teacher training or serving as an instructor of record for a course in my department.
- Being observed and evaluated as a teacher 3 times, including two Video Teaching Consultations (VTCs) in which my teaching in the classroom is recorded and reviewed together with CTL staff, and once where my teaching is observed, evaluated, and approved by a faculty member in my department.
- Completing a teaching portfolio (this document).

My experience of completing the above tasks for the CCT has been helpful not only for building connections in my community and improving my ability to teach in the context of my graduate studies at CU Boulder, but also for supporting the pursuit of my own professional development goals for the future. I hope to continue working in higher education upon the completion of my PhD, both as a researcher and as a teacher, in order to contribute to the betterment of the global academic community and to help train future generations. All the trainings, workshops, and events provided by the CTL have helped push me toward this goal, not only by providing formal training on best practices in the classroom, but also by giving me valuable guidance and practice on how to place these concepts in the context of my own teaching.

I should point out here that the CCT would have been just as valuable even if I chose (or later choose) not to pursue a career as a professor. As a physicist, any job I pursue, whether at a university, a government lab, a private research institute, a tech company, or an engineering firm, will require skills in communication, organization, and education to some extent. While some workshops I attended (like those on how to use clicker response systems effectively or how to implement alternative grading methods) were certainly designed specifically for those teaching classes in a university setting, other workshops (like those on achieving authority in the workplace, using humor in communication, or practicing empathy) have helped me more generally to become a better communicator and a better professional worker.

From the experience of pursuing the CCT, I have been able to learn just how vast the enterprise of educational excellence is and how much more room I have to grow through direct experience and learning from others. When I first came to CU Boulder, I thought I was already a great teacher, in part through my past experiences working as an educator at a science museum. However, when my teaching in the classroom was recorded for the CCT and I was given the opportunity to review my student interactions with much more experienced educators, I was astounded to see my many flaws and idiosyncrasies, and I quickly rose to the challenge of critically self-evaluating and incrementally improving my teaching. Fortunately, there is a broad field of research from educators who have tried just about every technique in the books, and I have discovered the immense value in keeping up to date with the education literature so that I do not need to reinvent the wheel every time I enter a new classroom.

For my future as an educator, some of the main lessons I have learned are that every classroom is different, every lecture and assignment requires careful planning, and every student deserves personal attention and interaction. I have taught the same course several times in a row for different sets of students and have seen completely different results, especially after the onset of the global COVID-19 pandemic. Some students learn best through repeated individual practice, some can only learn effectively through hands-on or in-person experiences, and some lack the necessary mathematical or conceptual prerequisites to learn at the same level as their peers, but they all can improve their knowledge and understanding through intentional interactions with both their classmates and the deliberate guiding hand of the instructor. In the future, I hope to continue communicating with others, experimenting, growing, and even making mistakes as a teacher, since these experiences offer wisdom in its purest form.

II. TEACHING PHILOSOPHY

Before stating anything else, I would first like to acknowledge that every role I perform as a physicist involves some form of teaching. Whether mentoring students engaged in a research project, communicating scientific results in an academic paper or at a conference, or standing in front of a classroom, every role a physicist plays is united by an academic teleology to discover and communicate knowledge in a way that others can understand and utilize. In what follows, I will focus on my perspectives on teaching as it pertains specifically to formal higher education. However, these philosophies will certainly see fruitful overlap with a wide variety of other communicative contexts, including (but not limited to) informal science education, primary/secondary education, and seminar presentation skills.

I've read enough teaching philosophy statements to know that while it is an easy task to construct and relay a list of statements that you agree with about teaching, it is much more difficult to construct a narrative that transforms these platitudes into a meaningful framework centered on one's own personal experiences. I will attempt to frame this narrative in the same way I would teach in the classroom—instead of simply compiling a list of important concepts and throwing them at the reader, I will center my story around a fundamental framework and highlight how each key concept relates to that framework, while also providing alternative viewpoints, interspersing my own personal experiences, and citing further resources when possible.

A Cognitive Model for Physics Education

Our methods of teaching have remained largely stagnant for most of the history of Western intellectual education, especially since the advent of the university a thousand years ago: an instructor gives a lecture in front of a group of note-taking students, occasionally asking questions of them (to evoke a tamed form of the Socratic method). However, modern society is changing rapidly. With the scientific method we can actually study how students learn best and incorporate these models into our teaching, and we additionally have access to new and innovative technologies that can either be detrimental or crucial for improved learning. But unfortunately, most new educational frameworks remain largely untapped by a majority of university professors.

Among the educational schools of thought that have arisen in modern times, I find myself most aligned with a **constructivist approach**, in which each student builds their own knowledge through active personal and social discourse (Mestre, 2020). This stands in contrast to the traditional liberal arts approach, in which students acquire knowledge passively through direct transmission from the instructor. Other theories of learning also exist (though we should be careful to note that a theory of *learning* does not necessarily equal a theory of *teaching*): in the behaviorist approach, focus is placed on external environmental factors and measurable achievement goals rather than internal mental processes, and in the sociocultural/radical approach, focus is placed on student autonomy and learning through practice within a community. Most of the physics education researchers at CU Boulder work within this latter framework, and through frequent interactions I have found merit in applying some of their methodologies in my own teaching.

The sum of my teaching philosophies might fit under the umbrella of a "cognitive model" for physics education (Redish, 2003). Within this model, there are 3 key concepts that I find are particularly important in my own teaching: (1) the necessity of **active learning**, (2) a focus on **conceptual understanding** in real-world contexts, and (3) a need to improve students' **attitudes about physics** rather than cover more content.

1. **Active Learning**: *I am a guide on the side, not a sage on the stage.*

"In the STEM classroom, should we ask or should we tell?" (Freeman, 2014). During the advent of the global pandemic in 2020, I and many instructors around me were faced with the possibility that we could post all our lectures online, provide students with ample homework problems, and sit back and let the rest of the semester take care of itself. But the overwhelming view from both students and teachers was that this was not enough—plenty of lectures could already be found online that were much higher quality than what I could cobble together over Zoom. What then was missing from these lectures that makes in-person education so valuable? The answer is active learning—I am not simply relaying content to students by *telling*, but I am *asking* them to construct their own knowledge, through both internal and external discourse.

When I first began teaching, I placed most of my focus on creating well-crafted presentations and lecture slides for my students. To be fair, this is precisely what my years as a student had trained me to do—the only teaching practice students usually get is with project presentations, graded for perfection. But my presentations had two negative effects: first, it meant I had to pour an immense amount of time into course preparation, and second, it meant that learning for the students was too easy. Students can't learn passively—instead, I would soon learn just how effective it can be to replace much of the work that I was putting into lectures with work that the students would need to put into grappling with the material themselves.

How have I practically implemented these goals of active learning? I work under the principle that students learn best through social interactions with their peers, applying Vygotsky's theories of development to a physics context (Jaramillo, 1996). For example, in CU Boulder's General Physics 1 & 2 classes, I have led recitations multiple semesters that involve practically no lecturing on my part. Instead, students work in small groups to complete tutorial workbooks first developed by researchers at the University of Washington (McDermott, 2001), while I travel from table to table asking students probing questions and nudging their discussions in the right directions. Even when I teach classes that only have a large lecture component and no recitations, I try to allot time at the end of each class (often over half of the total class time) for students to work in groups on tutorial-style comprehension assignments.

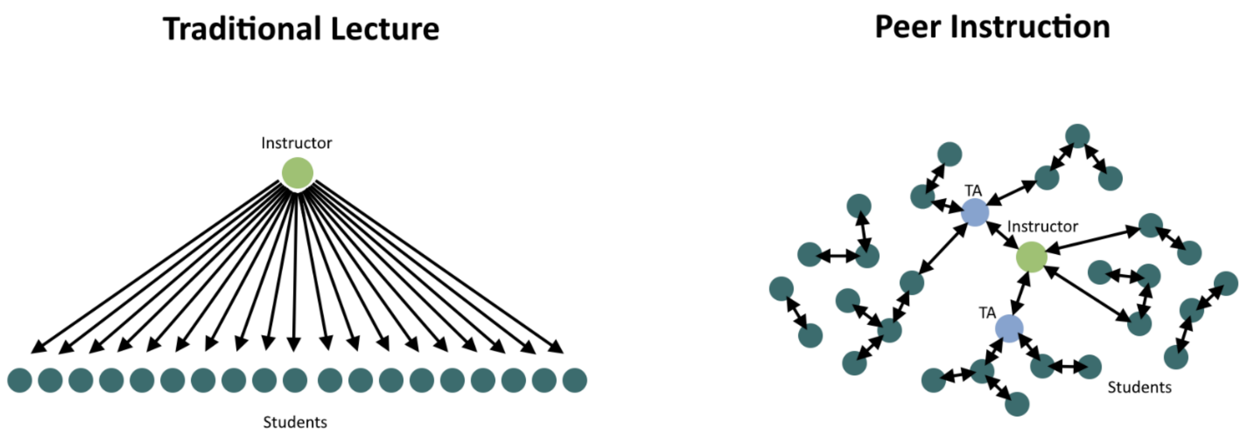


Figure 1: Traditional Lecture (left): students receive knowledge passively from the instructor. Peer Instruction (right): students learn actively from their peers in discussions facilitated by the instructor and any teaching assistants.

A useful framework for the facilitation of active learning that I often utilize is a methodology known as Peer Instruction (see Fig. 1) (Mazur, 1997). Under this framework, I pose a question that the students individually respond to through a clicker-based system (or some other evaluative means, like a Zoom poll or a simple show of hands). Then, students turn to their neighbors to discuss, and after a few minutes they are reevaluated with the same question (usually with substantial improvement) before I reveal the solution in a full-class discussion. With this approach, students are able to learn by doing and often by teaching their peers. They also learn to think like a scientist ("Why did you choose that answer?" "Anyone skeptical of their reasoning?").

One important thing I have learned about implementing active learning techniques in the classroom is that each use of the technique must be intentional and well-framed. Questions must be carefully constructed to allow for open-ended discussion—for example, in a large class for non-physics majors on the Physics of Light and Color, I found much more success framing questions to encourage scientific debate or Fermi estimation (e.g., "What color is a mirror?" "What would you see inside of a giant spherical mirror room?" "Roughly how many electrons are in your body?") versus questions that only required rote recall or algorithmic calculation (e.g., "What is the term for light bending through a medium?" "What is the frequency of light with a wavelength of 550 nm?").

Another way in which each use of active learning must be intentional and well-framed is in the implementation in the classroom. When I first began teaching, I (and many other instructors I know of) claimed to be "transforming the classroom" with clicker questions and new pedagogical practices, when in fact I was really putting up a question, hanging out in front of the classroom as the students sat in silence, and then eliciting one response from a student before stating the right answer and moving on. Clicker questions done poorly are only a waste of the students' and the instructor's time (Turpen, 2009). Instead, it is vital to set clear norms with the students from the beginning of the semester and continually help facilitate discussion among peers.

Plenty of other frameworks exist that I have implemented to elicit active learning in the classroom, such as Interactive Lecture Demonstrations (ILDs) that improve upon the traditional show-and-tell physics demos (Sokoloff, 2006). For an example of an ILD that

I created during a semester of virtual teaching of the Physics of Light and Color, see Appendix A.

I'd like to reiterate once more that the implementation of active learning pedagogy (and especially new technologies) is only helpful if done well. During my undergraduate physics education, we received access to Microsoft's novel HoloLens augmented reality technology for use in the upper-level electromagnetism course. We used the technology to visualize magnetic fields and forces in 3D space, but in the end, it was no help to our learning—interactions were mostly passive, and the visualizations made the learning too easy and lulled us into a false sense of understanding that wasn't reproduced once the technology was no longer available. Technological resources can be helpful, and I often use online tools like CU Boulder's PhET simulations with good effect, but these resources require careful framing and intentionality.

2. **Conceptual Understanding**: *Physics should describe the real world.*

The second key concept I find particularly important within the cognitive model of physics education revolves around the importance of conceptual understanding over abstract reasoning or rote memorization. Students often obtain an idealized view of physics that is completely separate from the real world ("Sure, at some point I worked through the geometry of how lunar phases work, but if you want an intuitive explanation, I'd say it's just caused by shadows") (Engeström, 1991).

To explain this further, I like to use an example adapted from Wason's four-card problem from the 1960s: suppose I have a deck of cards, each of which has a letter on one side and a number on the other. I place four of these cards in a row on the table, as shown in the left half of Fig. 2 (Redish, 2003).

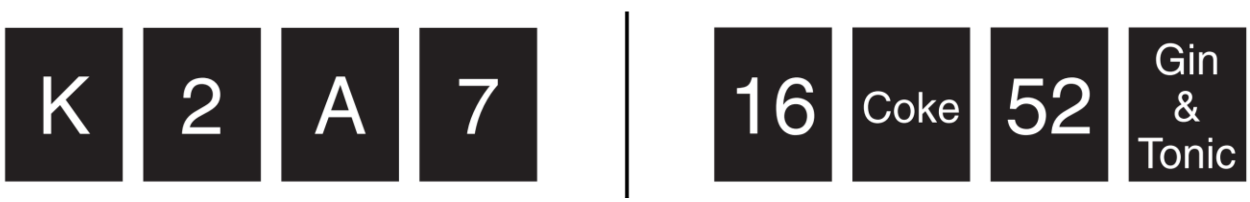


Figure 2: An abstract problem (left) and a more concrete problem (right)—see text.

Suppose I then make the following claim: *This set of 4 cards satisfies the property that if there is a vowel on one side of the card, then there is an odd number on the other.* How many cards do you need to turn over to be absolutely certain that the cards have been correctly chosen to satisfy this property?

Whenever I have shared this problem with my students or have seen it shared with other physicists, there is always some difficulty in solving the problem even after a minute or two of deliberation (note: the correct answer is that only the middle two cards need to be flipped). However, now consider the following problem.

You are serving as the chaperone and bouncer at a local student bar and coffee house. When patrons come in and give their order, the servers bring you a card with the patron's order on one side and their best guess of the patron's age on the other, so that you can decide whether to go and check their ID. A server drops four cards on the table.

They land as shown in the right half of Fig. 2. Which cards would you turn over in order to decide whether to go back to the table to check IDs?

Students usually have no problem answering this version of the puzzle almost instantly—you need to flip over the cards labeled “16” and “Gin & Tonic,” since you only care about underage patrons and alcoholic beverages. However, this problem is mathematically isomorphic to the previous one. Why is this version so much easier?

I appreciate this problem because it shows that students often handle knowledge and reasoning in very different ways depending on context. In one case they might rely on pure abstract mathematical reasoning, while in another case they might rely on reasoning based on social experience. In physics classrooms, students far too often use abstract reasoning devoid of any meaning to solve problems in a way that causes them to be good mathematicians but terrible scientists. Further, as an instructor, many concepts that feel familiar enough to us to be perceived as a “16/Coke/52/G&T” problem might seem to students like “K2A7.” We need to maintain patience and sympathy as we help students build physical intuitions and problem-solving skills one step at a time.

In every class I teach, I make sure to emphasize how each concept I teach applies to the real world. This emphasis is especially prevalent in a class I have taught a number of times at CU Boulder titled “Physics of Sound and Music.” In this class, the focus is shifted away from a mathematical or formulaic understanding of physics in favor of a conceptual understanding. Students do not simply use the Doppler effect formula to calculate frequencies; rather, they gain a physical intuition for why Doppler shifts happen and what the formula would qualitatively predict in different situations. To complement the concepts we discuss in class, I also developed a set of “homelabs” which allow the students to create, record, and analyze sounds in the real world around them, from measuring the speed of sound using a panpipe to estimating the size of a bird after recording its song. Examples of a few of the homelabs I developed are included in Appendix B.

By shifting the focus of instruction away from mathematical modeling and toward conceptual, physical intuition, I am able to get closer to the root of how students truly learn and acquire new knowledge about physics. In analogy to a Kuhnian notion of scientific change, students come to adopt new conceptual frameworks by passing through phases of *assimilation* (using their normal understanding to deal with new phenomena) and *accommodation* (replacing or reorganizing central concepts) (Posner, 1982).

In order for students to accommodate new conceptual frameworks, they must first be convinced that their previous conceptions are dissatisfactory, and that the new framework is both plausible and intelligible. This is the key to a concept-focused pedagogy—in General Physics 1, for example, one must recognize that many students come in with an Aristotelian view of motion, that heavier objects fall faster and that any motion will eventually settle into a more “natural” state of being at rest. In the language of diSessa, students piece together *phenomenological primitives* applicable to each problem at hand, such as “more effort begets more results” or “things die away,” and they never construct a systematic theory or worldview that allows them to address misconceptions and think like a true physicist (diSessa, 1988).

3. **Improving Attitudes about Physics**: *The hidden curriculum.*

The final concept I wish to elaborate on is one of the pioneering focuses of the Physics Education Research group at CU Boulder, how we as instructors can improve students' attitudes about physics. Despite having the best teachers and instructional methodologies, often the biggest takeaways students will have from a semester of rooting out misconceptions and having frequent discussion and debate with their peers is that physics is extremely counterintuitive and that it will never come naturally to them. Somehow there is a *hidden curriculum* that must be taught beyond the content knowledge of a particular course (Redish, 2003).

What needs to be conveyed to students beyond what is explicitly mentioned in a course's syllabus? Students should come away from a course with a *growth mindset* rather than a *fixed mindset*. They should be able to use sense-making to approach conceptual learning, and they should understand that physics must be understood as a connected, consistent framework that always applies directly to the real world. Additionally, they should acknowledge their own responsibilities in constructing their own understanding, through intentional metacognitive practices. And most importantly, they should develop a positive self-image to understand that physics is a diverse, social enterprise that can and should be taken on by any individual regardless of gender or ethnicity. These are the aspects of the hidden curriculum that should be taught in every physics class, implicitly or explicitly (I often take parts of class to have discussions solely about growth mindsets, metacognition, or the purpose of physics).

My gut instinct when teaching a group of students (especially non-physics majors) is to make physics seem as "flashy" or "entertaining" as possible—"Here is a really cool physics demo!" "Here are some beautiful equations that describe elegant symmetries in the Universe!" But the goal of physics is not to entertain, and while students might be impressed and captivated by an exploding hydrogen balloon or a tesla coil, they most likely will be impressed by the demonstrator rather than the physical concept being demonstrated. Instead, an instructor should create motivation by showing interest in the students. They should understand that we care about them and that their learning actually means something to us, and in this way, they will actually have a desire to learn and will be able to see themselves as a participant in the field.

One final idea worth mentioning relates to how a curriculum is developed for a course. The first time I taught "Physics of Light and Color," I planned out an ambitious semester covering all of the coolest aspects of light, based on what students wanted to learn about from a pre-semester survey. We would cover geometric optics, mirrors, photography, electromagnetism, the quantum nature of photons, and end the semester with a taster on Einstein's theory of relativity and black holes. But as the semester progressed, more and more content got delayed as I became more intentional about engaging in active learning and pushing the hidden curriculum. After having several discussions with other folks at CU Boulder working on physics education research, I realized the importance and necessity of a **radical reduction in content coverage**. There is no use in teaching more material if it slips right through students' fingers. That semester, I cut the content of the last quarter in half, focusing mainly on geometric optics and electromagnetism, and the students were all the better for it. They ended up retaining a deeper understanding of physics by the end of the semester, and they still all got to learn about the topics that most interested them.

In planning a curriculum, I like to make sure I am catering to the students' interests and passions, but only after we have developed a common framework of understanding in the course. Fig. 3 describes the type of curriculum I often envision: at first, students are given rigid expectations and structure for how they should approach their education, and once we have found common ground, the students are given more autonomy to embrace their own learning. And at the end of the semester, I often opt to give students a final project to complete on a topic of their choosing, since I find that this sort of deep learning turns out to be the main aspect of a course that students can remember five years later.

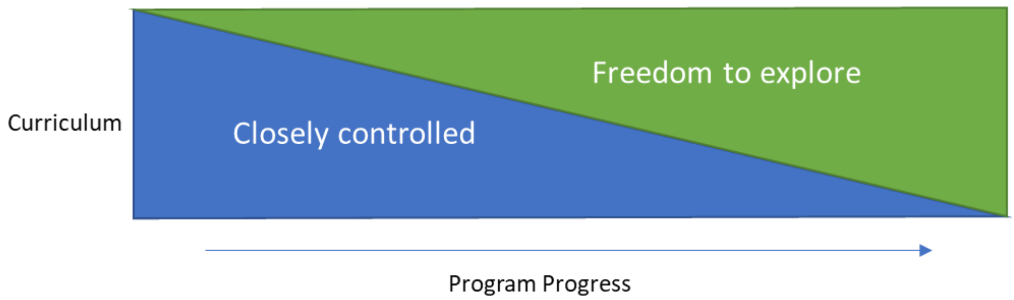


Figure 3: While students should be given clear expectations and norms at the beginning of a course, by the end they should be granted enough autonomy to explore just as a physicist would.

By utilizing active learning methods, focusing on a conceptual understanding, and pushing for improved attitudes about physics, I have been able to transform the classroom from a passive group of students taking notes on my laboriously constructed lectures into a thriving community of peers engaging in authentic, motivated self-construction of knowledge. By engaging with other instructors, I hope that I not only can continue ever improving my own teaching, but also that I can convey the necessity of improved pedagogy to others in order to transform the entire department into a thriving community of supported education (Henderson, 2007). A path toward better education is out there; we just need to support and drive one another to give students the best possible experience we can offer.

III. ASSESSMENT PRACTICES

No teacher is perfect, and no student is perfect. The only way that we can come to a mutual understanding when teaching and learning physics is through consistent assessment, both **formative** (low-stakes feedback on student learning and instructional effectiveness) and **summative** (high-stakes evaluation of student learning against some benchmark for a grade).

1. Formative Assessment

The evaluation of student learning for no grade can take on many forms. As a teacher, I most often implement formative assessment by **posing frequent questions** during classes. The crudest form of this practice involves consistently asking students if they have any questions after every slide of material I present. Such a simple addition to a lecture can have profound effects in establishing a norm of open communication between the students and the teacher and making it clear to them what my motivations are as a teacher.

But beyond this crude form of assessment, I also make sure to ask specific content-based questions of the students—as noted in the previous section, students learn best when they are given the opportunity to construct their own knowledge. And not only do the students learn more when I assess them in this way, but I also can see how well I have framed a given concept and whether I need to spend more time discussing it with the students before moving on to a new concept.

Whenever I implement clicker-based questions in my classes, my form of peer instruction usually falls under the category of formative assessment. Instructors will often make clicker questions a part of students' grades (either as a participation credit or as credit for correctness), and when I began teaching I initially followed this practice. However, it soon became clear to me that assigning grades for clicker questions did not substantially improve student learning. When questions were graded for correctness, students would focus more on getting the right answer than on understanding the underlying concept. Conversely, when questions were graded for completion, students were more likely to do the bare minimum (e.g., only show up to class and log into the clicker app to record their attendance, or answer "A" for every question). By removing the grading component entirely, I found that students felt more autonomy to learn the material well, and miraculously, they were still just as willing (if not more willing) to answer the clicker questions and engage in discussion, even without the incentive of being graded.

In addition to the oral forms of assessment described above, I also like to include **written formative assessments** throughout my courses. Around the middle of the semester and again at the end of each semester, I give my students optional surveys on how my teaching is going, how the course pace is for them, and how I can better support them in their learning. Each cohort of students I teach faces different challenges and utilizes slightly different styles of learning, so these surveys never remain fruitless for informing how I conduct my teaching. But more importantly, they give the students a chance to self-evaluate their own learning throughout the course so that they can be motivated to engage with the content in the best way possible. Aside from creating my own surveys, the university also administers Faculty Course Questionnaires (FCQs) at the end of each semester. The FCQ results from when I taught “PHYS 1240: Sound and Music” in Fall 2023 are shown in Appendix C, along with select results from previous times I taught the same course for context (and to demonstrate my growth as an instructor).

In light of the 3rd point in my teaching philosophy In Sec. II about improving students’ attitudes about physics, I have also administered surveys centered around epistemological beliefs and course-specific expectations. Physics education researchers at CU Boulder created and validated such a survey known as CLASS that is used throughout the nation (Adams, 2004). While teaching “PHYS 1230: Light and Color,” I administered another broader survey, “Epistemological Beliefs Assessment for Physical Sciences” (EBAPS), twice during the semester (Elby, 2001). The contents of that survey and an analysis of the results are presented in Appendix D.

While optional written surveys work well once or twice in a semester, I have also found success with one final form of written assessment that occurs more frequently. During a time of remote instruction in 2020, I was motivated by the work of Eric Mazur, who included something akin to the following question at the end of all of his pre-lecture online reading assignments (Crouch, 2001):

> *What did you find difficult or confusing in today's class? If nothing was difficult or confusing, tell us what you found most interesting.*

I began to include this question in all my daily online post-class quizzes for the students, making it clear that the students could write whatever was on their minds without any effect on their grades. I regularly used the results from these assessments to help gauge how well the students were learning and which of my teaching practices (e.g., visual demos, group work, etc.) work best for the students.

Despite the utility of formative assessment from students, it is worth noting that students aren’t always the best judges of their own education. An instructor may be highly rated by students for well-polished lectures and for ease of understandability, yet those same students might do worse on standardized assessments than those taught by a less well-received instructor (Redish, 2003). Thus, I also rely on support and **feedback from other instructors and peers**. During meetings with the learning team for my courses (at CU Boulder, this team can include graduate student “TAs” and undergraduate “LAs”), I always make sure to ask about their interactions with the students, how their office hours are going, and what things they’ve noticed about the class or my teaching that I might not be aware of.

Along these lines, I should mention that the CCT necessitates ample formative feedback via a set of Video Tape Consultations (VTCs), in which my teaching is recorded by a faculty or staff member and subsequently reviewed and analyzed together with me. I have never been one to enjoy recordings of myself—I have vivid memories in my younger years of refusing to listen to recordings from my parents of me playing in a piano recital or giving a school presentation. And yet, these VTCs not only opened my eyes to my flaws, but also helped me gain confidence in my ability to teach well. During the first VTC, I had fruitful discussions with the consultant about how to exude authority and about increasing wait times. And during the second VTC, I learned how to create a better culture in the classroom—the students had settled into norms of late arrivals, remaining silent when asked questions, and generally lacking communication; following that VTC I had actionable ways to navigate silence in the classroom and promote both metacognition and communication among students.

2. Summative Assessment

The first time I was given the opportunity to be the primary instructor for a class, I realized I had to choose how my students should be assessed for a final grade. My philosophy on final exams has changed substantially throughout my time at CU Boulder. For my first course, I was handed down **multiple-choice exams** from past instructors, and I used these unashamedly. The students did fine, and I learned about their performance well enough, but something didn't sit right with me—students were being trained to bubble in correct answers, *a skill which is never reproduced in the real world*. Is this really the takeaway that I want to give to my students, that physics is ultimately just about choosing the right answer from a set of options?

I soon switched to a completely different format of final assessment. Thinking back to my own education, I realized that the aspects of a course that I retain the most after several years pass (and the aspects that I appreciated and enjoyed the most) were **final projects**, the deep study of a specifically chosen piece of the course's curriculum. I implemented final projects with great success in several physics courses I taught for non-majors, allowing students to choose a topic which interested them and write a research paper related to that topic. I also required a hands-on component to the project to emphasis the experimental nature of physics and the importance of real-world connections to what was taught in the classroom. In a class on the physics of sound and music, students built speakers out of paper plates, measured the soundproofing properties of different rooms in their houses, and calculated the speed of sound using the Doppler effect. These projects often brought together several independent concepts taught throughout the semester, and the students appreciated the autonomy in learning.

However, when I taught a project-based course with no exams, I began to notice a severe lack of motivation in the day-to-day habits of my students. This is the paradox of formative assessment: despite all the benefits of project-based assignments and other alternative assessment practices, the one sure-fire way to motivate students to study outside of class time is with a traditional exam. Whenever I institute an exam, students flock to office hours, work harder on homework assignments, and ask more questions during lectures. I did not want to return to having a simple multiple-choice final exam, but some form of real-time summative assessment was needed.

Though I do not have a universal solution for how final assessment should be done (surely it should be context-dependent based on class size, curriculum level, etc.), several new options I have used and/or experienced have worked well. During the COVID-19 pandemic, when courses were fully online, I gave students a take-home exam for "PHYS 1240: Sound and Music" that was entirely free-response. The task for the students was to analyze a recording I had crafted purporting to be from an alien planet in the same style as the Voyager golden record (which we had discussed extensively in class). The students had to synthesize concepts from each unit in the course, measuring frequencies and spectra, calculating the speed of sound on the planet, analyzing musical scales, and considering the universality of the physics concepts discussed throughout the semester. The exam was received well—it gave the students the opportunity to express both knowledge and creativity (the latter of which is often suppressed in physics education), and it easily helped distinguish to what degree each student had internalized the key concepts required for the course.

CU Boulder's Physics Department has also had great success implementing **two-stage exams** in all their introductory physics courses (Wieman, 2014). After completing a slightly shortened version of a traditional exam, students are given the opportunity to work in groups to retake a select portion of the exam so that they may regain partial credit. Every student I have talked to has expressed an overwhelmingly positive opinion about how the exam setup helps to ease anxiety and gives them the opportunity to learn and solidify their understanding in a deep way.

In the end, assessment only gives instructors a partial view of students' learning—in analogy to the concept in physics of refraction (Fig. 4), the knowledge passed from instructor to student may become distorted or change directions by the time a student internalizes and applies it to their life. However, the instructor is only able to access the part of learning that is reflected back from the students on an exam. There often can be an impedance mismatch between the instructor and students, so it is absolutely vital that feedback and assessment is both frequent and comprehensive to ensure that the instructor and students alike can gain from the experience of the course.

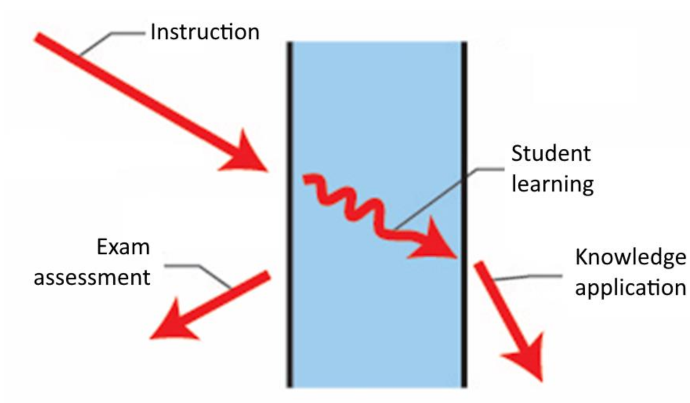


Figure 4: Diagram showing the process of instruction, feedback, and student learning, in analogy to physical refraction through a barrier.

IV. DIVERSITY STATEMENT

In the words of Albert Einstein, “We must not only learn to tolerate our differences. We must welcome them as the richness and diversity which can lead to true intelligence.” Though Einstein is often painted as a quintessential *old white male physicist*, he was actually a Jewish refugee and passionate civil rights activist, and he often used his influence and his finances to support the marginalized. He even regularly took strolls through the segregated African-American neighborhoods of Princeton to chat with folks and hand out candy to children. Why care so much about diversity, especially for a ”hard science” discipline that is often claimed to be completely objective and devoid of social influence?

The answer is that physics *is* inherently a social discipline, just like any other field of research conducted by and communicated for people. We come to learn about the Universe only by working together as a community. With this in mind, we cannot ignore the fact that physics has developed its own culture and is easily influenced by the perspectives of its constituents that have the most power.

In an open letter to the U.S. Supreme Court signed by over 2,000 physicists in 2015 defending affirmative action, the authors note that the lack of underrepresented minorities in physics is a serious problem not only for the flourishing of the community’s members, but also to maintain respect and unity with the broader makeup of humankind. They also argue that “it is the social experience of minority students that is more likely to make them drop out, rather than a lack of ability” (Corrales, 2015). We therefore must focus on fostering a positive social experience for all physicists and aspiring physicists through inclusive and equitable practices.

Despite my own limitations as a white, heterosexual male to provide a voice for the marginalized, I make an effort to do everything I can to promote diversity, equity, and inclusion in my **research**, in my **teaching**, and in **service** to the departmental community. For example, when writing academic papers, I always make sure to adhere to principles of universal design in both the content (i.e., reducing jargon and presenting a clear story) and presentation (e.g., choosing color schemes for figures that are accessible for those with color vision deficiency).

In the classroom or lecture hall, I as a teacher have an immense responsibility to establish a positive culture of respect and communication. I always allow for ample student discussions among peers, I try not to call on the same “teacher’s favorites” during every lecture, and I use inclusive language (e.g., avoiding using only male pronouns in examples or saying “this guy” when referring to part of an equation or diagram). The classroom should be a place where everyone is welcome to participate equally and free to express their ideas to one another. Additionally, I try to include historical context in many of my lessons, not only to show how certain minorities have been treated or viewed in the past in the realm of physics, but also to highlight key contributions from female scientists like Jocelyn Bell, Sophie Germain, or Rosalind Franklin that are often overlooked in standard physics curricula.

Throughout my time in graduate school, I have also played an integral role in helping build a positive, welcoming community within the Physics Department. There are small, day-to-day practices I engage in like organizing lunch outings or regularly checking in with colleagues, but I have also worked substantially in larger organizational settings. In 2022, I founded the "Grand Canonical Ensemble," an informal musical ensemble open to any member of the physics community, which has flourished with semesterly concerts and, based on testimonials, has allowed students and postdocs to develop long-term friendships with peers they would never have met in an otherwise isolated institution. Additionally, I recently collaborated with members of various student organizations and successfully earned a $38k innovation grant in order to host a poster symposium and fund research fellowships for underrepresented minorities in the Physics, Math, and Astronomy Departments at CU Boulder.

A final aspect of service that has played a crucial role in my experience as a graduate student is my involvement with the group CU-Prime, a student-led chapter of the NSF-funded national organization known as the Access Network. Twice I have taught the CU-Prime-designed course "Fundamentals of Scientific Inquiry" intended to introduce incoming, and especially minoritized, physics students to what it means to be a scientist and do research in practice (see Appendix E for the syllabus the last time I taught it). CU-Prime also hosts a mentorship program between graduate and undergraduate students, and for the past several years I have also led CU-Prime's biweekly talk series, designed both to support graduate students in becoming effective presenters and to introduce undergraduates to research and potential career paths in a jargon-free way. Through these programs and many more (e.g., I initiated an annual pumpkin-drop event and an annual large-scale physics debate that still are running to this day), I have tried my best to foster a positive, equitable community wherever I am.

V. CURRICULUM VITAE

Tyler C. McMaken
Last updated 25 Mar 2024

Personal website: **jila.colorado.edu/~tymc8291/**

Email address: **tyler.mcmaken@colorado.edu**

Office: **A901, JILA, CU Boulder**

Mailing address: **JILA & Department of Physics**
University of Colorado
Boulder, CO 80309-0390

Education

University of Colorado Boulder, Boulder, CO — **2018 – Present**
MS in Physics, 2020
PhD in Physics anticipated August 2024

Case Western Reserve University, Cleveland, OH — **2014 – 2018**
BA in Physics, BA in Music (piano, organ, harpsichord) — GPA: 4.0/4.0
Minors in Astronomy, Mathematics

The Ohio State University, Columbus, OH — **2013 – 2014**
PSEOP (pre-baccalaureate program) — GPA: 4.0/4.0

Research Experience

University of Colorado Boulder, Dept. of Physics, Boulder, CO — **2019 – Present**
PhD thesis. Advisor: Prof. Andrew Hamilton.
Modeling the interior of astrophysical black holes with rotation and accretion, using both classical and semiclassical physics.

Case Western Reserve University, Dept. of Physics, Cleveland, OH — **2017 – 18**
Undergraduate capstone thesis. Advisor: Prof. Glenn Starkman.
Constraining cosmic topology by analyzing the correlation matrices of the CMB for generalized flat fundamental domains.

University of Notre Dame, Dept. of Physics, South Bend, IN — **Summer 2017**
Research Experience for Undergraduates (REU). Advisor: Prof. Umesh Garg.
Analyzed data from Gammasphere at Argonne National Laboratory to determine angular distributions and mixing ratios for ^{135}Pr nuclei.

National Solar Observatory, Boulder, CO — **Summer 2016**
REU. Advisor: Dr. Gordon Petrie.
Studied the helicity distribution and global impact of a solar active region, attended 2016 conference of AAS Solar Physics Division and published article in *The Astrophysical Journal.*

Publications

McMaken, T. & Hamilton, A. J. S. (2024). "Hawking radiation inside a rotating black hole" *Phys. Rev. D*, 109, 065023.

McMaken, T. (2023). "Pancakification and negative Hawking temperatures" *Int. J. Mod. Phys. D*, 32, 14, 2342017.

Jhurani, K. & **McMaken, T.** (2023). "Existence of time-like geodesics in asymptotically flat spacetimes: A generalized topological criterion" *Adv. Stud. Theor. Phys.*, 17, 3, 109-120.

Hamilton, A. J. S. & **McMaken, T.** (2023). "Unification of the four forces in the Spin(11,1) geometric algebra" *Phys. Scr.* 98, 085306.

McMaken, T. (2023). "Semiclassical instability of inner-extremal regular black holes" *Phys. Rev. D*, 107, 125023.

McMaken, T. & Hamilton, A. J. S. (2023). "Hawking radiation inside a charged black hole" *Phys. Rev. D*, 107, 085010.

Hamilton, A. J. S. & **McMaken, T.** (2022). "Wave equations in conformally separable, accreting, rotating black holes" *Phys. Rev. D*, 106, 124031.

McMaken, T. & Hamilton, A. J. S. (2022). "Renormalization of $\langle \phi^2 \rangle$ at the inner horizon of rotating, accreting black holes" *Phys. Rev. D*, 105, 125020.

McMaken, T. (2022). "Notes on primordial black hole origin for thermal gamma-ray bursts" *MNRAS*, 511, 1, 1218–1223.

McMaken, T. & Hamilton, A. J. S. (2021). "Geometry near the inner horizon of a rotating, accreting black hole" *Phys. Rev. D*, 103, 084104.

Sensharma, N. et al. (2019). "Two-phonon wobbling in 135Pr" *Phys. Lett. B*, 792, 170-4.

McMaken, T. & Petrie, G. (2017). "The Great Solar Active Region NOAA 12192: Helicity Transport, Filament Formation, and Impact on the Polar Field" *ApJ*, 840, 100.

Presentations

Invited

"Why you should care about what happens inside black holes"
APS Friday Lunch Seminar, Dept. of Astrophysical and Planetary Sciences, CU Boulder, September 2023.

"Hawking radiation and semiclassical singularities inside black holes"
Center for Gravitation and Cosmology, Yangzhou University, Jiangsu Province, China (virtual), April 2023.

"Just how black are black holes?"
CU-Prime Talk Series, CU Boulder, September 2021.

"20,000 leagues under the ringularity: What's inside of a black hole?"
CU-Prime Talk Series, CU Boulder, September 2019.

Contributed

"Negative-temperature Hawking radiation near the inner horizon, the outer horizon, and beyond"
APS April Meeting 2023, Minneapolis, Minnesota, April 2023.

"The singularity at the inner horizon of astrophysical black holes"
32nd Midwest Relativity Meeting, APS Division of Gravitational Physics (DGRAV), Oakland University, Michigan, October 2022.

"Renormalization of $\langle\phi^2\rangle$ at the inner horizon of rotating, accreting black holes"
APS April Meeting 2022, New York City, New York, April 2022.

"Geometry near the inner horizon of a rotating, accreting black hole"
APS April Meeting 2021, virtual, April 2021.

"Black hole interiors: Mass inflation and BKL collapse"
Black Holes Meeting, CU Boulder, November 2019.

Posters

"Hawking radiation around and inside rotating and accreting black holes"
Quantum Effects in Gravitational Fields, Leipzig University, Germany, August 2023.

"Evidence for Two-Phonon Transverse Wobbling in ^{135}Pr"
2017 Fall Meeting, APS Division of Nuclear Physics (DNP), October 2017.

Media Mentions

Mann, Adam. "Black Holes Evaporate—Now Physicists Think Everything Else Does, Too." *Scientific American*, 22 June 2023.

Hughes-Castleberry, Kenna. "What Happens When You Fall into a Black Hole?" *JILA Light and Matter*, 12 April 2023.

Grants & Fellowships

International Travel Grant **Fall 2023**
CU Boulder Graduate School

Ray Mace Smith Graduate Fellowship **Spring 2023**
CU Boulder, Dept. of Astrophysical and Planetary Sciences

Graduate Student Travel Grant (2x) **Spring 2023**
CU Boulder, Dept. of Astrophysical and Planetary Sciences **Summer 2023**

Dissertation Completion Fellowship **Fall 2022**
CU Boulder Graduate School, one semester of full funding

Domestic Travel Grant **Spring 2022**
CU Boulder Graduate School

Division of Gravitational Physics (DGRAV) Travel Grant **Spring 2022**
American Physical Society

Carl Hansen Graduate Fellowship **Fall 2021**
CU Boulder, Dept. of Astrophysical and Planetary Sciences

NSF GRFP: Honorable Mention **Spring 2020**
National Science Foundation's Graduate Research Fellowships Program

Richard and Peggy Notebaert Fellowship (declined) **Spring 2018**
University of Notre Dame, 5-year graduate fellowship & full tuition coverage

Conference Experience for Undergraduates Award Funding **Fall 2017**
American Physical Society Division of Nuclear Physics (DNP)

Awards & Honors

Dean's Innovation Fund Award **2024**
College of Arts and Sciences, CU Boulder, $38,720
For the co-development of "Research Beyond Borders: Poster Symposium and Research Fellowship for Underrepresented and Minority Groups in STEM"

Gravity Research Foundation 2023 Awards for Essays on Gravitation **2023**
Honorable Mention

R. N. Thomas Award **2022**
JILA, CU Boulder, $3,000

Physics Award for Outstanding Graduate Student Service (2x) **Spring 2023**
CU Boulder Dept. of Physics **Fall 2021**

Physics Award for TA Excellence **Fall 2020**
CU Boulder Dept. of Physics

Graduate Part Time Instructor Appreciation Award **Fall 2020**
CU Boulder Dept. of Physics

Golden Key Scholar **2018**

Phi Beta Kappa Scholar **2017**

National Society of Collegiate Scholars **2015**

National Merit Scholar Finalist **2014**

Teaching Experience

University of Colorado Boulder, Dept. of Physics, Boulder, CO **2018 – Present**

Teaching Assistant (TA)

PHYS 1110 "General Physics 1" (Fall 2018)
PHYS 1120 "General Physics 2" (Spring 2019, 24)
PHYS 1240 "Sound and Music" (Spring 2020; Fall 2020)
PHYS 4450/5450 "History and Philosophy of Physics" (Spring 2024)

Course Instructor

PHYS 1110 "General Physics 1" (Summer 2024)
PHYS 1230 "Light and Color" (Spring 2021)
PHYS 1240 "Sound and Music" (Summer 2019, 20, 21, 22; Spring 2022, 23; Fall 2023)
PHYS 1400 "Fundamentals of Scientific Inquiry" (Fall 2019, 21)

Mentored Students

Devayani Ravuri, *Physics undergraduate, CU Boulder* **2023 – Present**

Honors Thesis project: "The gravitational redshift in the Hawking radiation perceived by an observer falling into a Reissner-Nordström-de Sitter black hole"

Krish Jhurani, *Homestead HS, Cupertino, CA* **2023**

Independent research project: "Exploring Time-Like Geodesics in Asymptotically Flat Spacetimes"

Service & Community Outreach

Journal Peer-Reviewer **2022 – Present**

Monthly Notices of the Royal Astronomical Society (*MNRAS*)
The European Physical Journal C (Particles and Fields)

Grand Canonical Ensemble, CU Boulder **2022 – Present**

Founded a physics community music ensemble involving weekly rehearsals and semesterly concerts under the dome at the Fiske Planetarium.

CU-Prime, CU Boulder **2019 – Present**

Student-led chapter of the national Access Network focused on education and DEI efforts in physics. I currently run a bi-weekly talk series and maintain the website and YouTube channel. I also co-taught the course developed and run by CU-Prime (PHYS 1400) twice.

Science Under the Dome Series, Fiske Planetarium, Boulder **2023**

Presented an hour-long public show at the Fiske Planetarium on sound and astronomy titled, "Music of the Universe."

Discovery Concert Series: *Soundsational Science*, Boulder, CO **2023**

Collaborated with the Boulder Philharmonic Orchestra to design and teach in an educational concert program series for ~1,000 middle school students on the topic of the science of sound.

Physics & Astronomy Club, Case Western Reserve University **2014 – 2018**

PR Chair for student-led club that promotes the interest of physics and astronomy to community through talks, trips, demo days, etc.

Center of Science and Industry (COSI), Columbus, OH **2012 – 2015**

Experience Programs Teacher (2015), Floor Faculty Apprentice ('12-'14), Volunteer ('08-'12)

Performed science shows and demos, interacting with and educating museum guests. Volunteered for over 1500 hours before leading, teaching, scheduling, and mentoring new volunteers.

VI. APPENDICES

Appendix A: Interactive Lecture Demonstration (ILD) on Electromagnetic Radiation, Designed for PHYS 1230: Light and Color

On Thursday of Week 13 during the Spring 2021 iteration of PHYS 1230: Light and Color, our class had an Interactive Lecture Demo format, with four experiments related to electromagnetic radiation that the students made predictions about and analyzed. Below is the Canvas assignment that was given to each student. The students worked in Zoom breakout rooms of 3-4 people each to complete each question (mostly formatted as essay responses) one at a time.

Today, our class is formatted as an Interactive Lecture Demo. This means that the participation assignment must be completed in steps as the lecture progresses along, and you will be predicting, observing, explaining, and analyzing what happens in each demo.
Unlike previous participation assignments, you will only be given one question at a time, and you will not be allowed to backtrack. Many of the questions are assigned a point value of 0, since you will be graded for effort, not accuracy. But if I see blank or nonsense answers, I reserve the right to deduct points retroactively from your score.

1. Our first piece of equipment is a camera capable of detecting a mystery wavelength of light somewhere between the micrometer and nanometer range (this range partially overlaps with what we would call visible color).
   HYPOTHESIZE: Based on what you can see through the camera, what can you say about how this specific type of light is produced? What sorts of things shine bright, and what sorts of things don't shine at all?
2. PREDICT: What do you think you will see through this camera when an incandescent bulb is turned on? What about when red, green, and blue filters are placed in front of the bulb (each separately, and/or in various combinations)?
3. OBSERVE what happens.
   EXPLAIN: Based on what you have observed, what wavelengths of light can we rule out? (i.e., the camera CANNOT be imaging at those wavelengths)
   - ☐ X-ray (∼1 nm)
   - ☐ Ultraviolet (∼100 nm)
   - ☐ Blue (∼450 nm)
   - ☐ Green (∼550 nm)
   - ☐ Red (∼700 nm)
   - ☐ Infrared (∼1000 nm)

4. Based on our observations, we can guess that our wavelength is somewhere just outside the visible range (if your previous answers disagree, discuss with your peers to try to understand why).
   ANALYZE: What wavelength of light is the most likely candidate for this camera (infrared vs ultraviolet)? What observational evidence leads you to that conclusion?
   Or if you're still unsure or don't think we have enough information to tell, what experiment could you conduct to determine which wavelength the camera detects?
5. Next, we will consider microwaves.
   PREDICT: What do you predict will be seen with the infrared camera when the array of marshmallows are radiated with microwaves?
6. OBSERVE what happens.
   EXPLAIN: Based on what you have observed, why do you think you are seeing what you see?
7. ANALYZE: This microwave oven operates at a frequency of 2.45 GHz. Based on your observations, calculate the speed of light, in units of mm·GHz (millimeters*gigahertz, which is the same as a million m/s).
8. Finally, let's look at some radio waves.
   PREDICT: What do you think will happen if the antenna with the light bulb is rotated until it is vertical instead of horizontal?
9. OBSERVE what happens.
   EXPLAIN: Why do you think the light bulb behaved as it did? Be specific.
10. ANALYZE: Based on our measurements, what order of magnitude frequency does this radio transmitter operate at, in Hz? Give your answer as a power of 10; i.e., if you think the frequency is around 10^5 Hz, you would enter the number "5".
11. Our last pieces of equipment are the radio player and the Tesla coil.
    PREDICT: What do you think you will hear if the Tesla coil is turned on while the radio player is tuned to a static AM frequency?
12. OBSERVE what happens.
    EXPLAIN: Why do you think you heard what you heard?
13. What did you find difficult or confusing in today's class? If nothing was difficult or confusing, tell us what you found most interesting. (Write at least a sentence or two, but no more than a paragraph.)

Appendix B: Homelab Assignments Designed for PHYS 1240: Sound and Music

In what follows are three "homelab" assignments I developed for used in the non-majors course "PHYS 1240: Sound and Music." The assignments were given every two weeks during the semester and allowed students to engage with the course material in a hands-on way. The three assignments included below are, in order:

- Homelab #5, Fall 2023: *Record birdsong and analyze the spectrogram.*
- Homelab #2, Spring 2022: *Explore CU's PhET simulation on Fourier synthesis.*
- Homelab #5, Summer 2020: *Measure the reverberation time in your room.*

Homelab #5

PHYS 1240: Sound and Music
Fall 2023

due Thursday, November 9, 2023 (by the start of class)

Instructions: Underlined portions indicate what you need to include in your submission. Either type up your answers, or write them down on the answer form provided in class. Upload your work online to Canvas. Be sure to show all your work (show how you get your answers), since physics isn't just about getting the right answers, but rather about the process of reasoning through problems and your ability to demonstrate that reasoning to others.

In this homelab, you will study the physics of birdsong, making your own recording of a bird's vocalizations and analyzing its acoustical properties to determine the bird's size.

Step 1: Use your phone or another recording device to make an audio recording of a bird's song/call. This can be any type of bird, as long as you are able to get a clear sample of at least one of its vocalizations in full. Try your best to isolate a single bird's call from others in the recording, and it may help to get away from traffic to reduce the noise. Don't worry if you aren't able to see or identify the bird—we will only be concerned with analyzing the sounds it makes.

Step 2: Once you have your recording, upload it to Audacity (if it's a video, it must first be converted to an audio file, which can easily be done online) and look at the spectrogram. Adjust the spectrogram settings until you can clearly see what's going on in the recording, and play it back to make sure the features you can see correspond to the bird you can hear. Then, on your answer form, make a sketch of your spectrogram (or include a screenshot in your submission). Be sure to properly label and number your axes, with the appropriate units, and sketch the main features you think are relevant. Alternatively, you may choose to make a screenshot of the spectrogram, type up your remaining answers, and print out your answers for submission, but this is not required.

Step 3: Next, analyze your spectrogram, including as much of the following information as you can (note that every recording will be different, so don't worry if some of the features below aren't present for your bird—just describe what you think would be most important to fully characterize the sound in your own words):

a. First, as a scientist, it's good practice when making field recordings to include the time and location of your recording (not necessarily GPS coordinates, but just a short description of where you were, the time of day, etc.). If you could see the bird, also include a visual description of what it looked like.
b. Qualitative features of the recording: What does it generally look like? Is there a harmonic series, is it a pure tone, or does it look more like rough noise? Do any lines go up, down, both, or stay flat? Is the vocalization a trill, a whistle, a chirp, or something else?
c. Quantitative features of the recording: How long is the bird's call/song? If it's a repeating pattern, what's the duration of one unit? What frequency range (high-low) is represented in your recording, and what might you say is the bird's fundamental frequency?

In your analysis, think about how your bird is able to produce the sound it does. Birds have double-branched vocal cords (called a "syrinx") in contrast to our single-branched larynx, so you may see in the spectrogram evidence of the syrinx being used in a way that's different from our larynx—this might happen if two lines occur at the same time running in different directions, or if a line suddenly switches direction without prior notice.

Step 4: Finally, use your recording to estimate the effective length of your bird's vocal tract (from syrinx to beak). You can model this as a column of air in a closed-open tube, so you should be able to pick out a frequency from the recording that might represent the fundamental frequency of such a tube. This may be easy if your recording has a single pure tone (just use the frequency of that line) or a harmonic series (just choose the lowest line as your fundamental frequency), but if your bird produced only noise or otherwise has tones spanning a large range of frequencies, choose a frequency on the lower end of the range, since birds often change higher frequencies by opening their beaks wider, departing from an idealized tube model. Once you have a fundamental frequency f_1, calculate the length L of the vocal tract using the formula for a closed-open tube:

$$L = \frac{v_s}{4f_1}.$$

For the velocity, use 355 m/s—birds have a higher metabolism than humans and therefore a higher body temperature, at about 105°F. Express your answer in centimeters (cm). Does this number make sense compared with the size of your bird? If not, why might it not be perfect?

Homelab #2

PHYS 1240: Sound and Music
Spring 2022

due Thursday, February 10, 2022 (3:30pm MST)

Instructions: Underlined portions indicate what you need to include in your submission to Canvas. Either type up your answers, or write them down and scan your work to a PDF. Be sure to show all your work (show how you get your answers), since physics isn't just about getting the right answers, but rather about the process of reasoning through problems and your ability to demonstrate that reasoning to others.

Fourier Synthesis

Go to CU's PhET simulation titled "Fourier: Making Waves." Once you've opened the applet, click "Discrete" and do some exploring. The bottom graph shows the total pressure amplitude of a sound wave as a function of distance, the middle graph shows a set of sine waves that add together to produce the bottom graph, and the top graph shows the maximum amplitude of each of those sine waves. Try clicking and dragging to adjust these amplitudes (these intensities of the note's harmonics are called the Fourier coefficients). To see examples of different complex wave sums, change the dropdown menu on the right labelled "Waveform" from the default "sinusoid" to another type of wave, like "square." You may then hear the wave by checking the box beside the ♫ symbol.

1. First, restore the simulation to its default settings—the top graph should have A_1 set to 1.00 and A_2 through A_{11} set to 0. Then, set the amplitude A_8 on the top graph to 0.50, and see how the wave sum at the bottom changes. Additionally, set the amplitude A_4 to 1.00. Compare the middle and bottom graphs and note that in the middle of the graph at $x = 0$, all three waves have a value of 0, so the sum is also 0. Sketch what the bottom graph looks like on your answer form. Be sure to include labelled axes with numbers, as is presented in the simulation.

In the right panel under "Measurement Tools," check the box labelled "Wavelength" and click the right arrow until λ_4 appears. This shows the wavelength of the fourth harmonic (the green sine wave, which you gave a maximum amplitude of 1.00). What is the wavelength of the fourth harmonic, in meters? Label your answer on your sketch by drawing a line to indicate its size (as is done in the middle graph) and writing "$\lambda_4 = \_$ meters" (where the value of the wavelength goes in the "__").

2. Next, take all the amplitudes to zero, and set both A_{10} and A_{11} to 1.00. With these settings we can see the phenomenon of beats. At $x = 0$, the waves perfectly line up and interfere constructively (doubling the total amplitude), and at $x = \pm 0.5$, the waves destructively interfere and cancel out. To see the full pattern, zoom out all the way by clicking the minus sign at the bottom right of the Sum graph 4 times. Sketch what the bottom graph looks like on your answer form. Again, be sure to include labelled axes with numbers, this time with the x-axis going from $x = -2$ meters to $x = 2$ meters.

3. In his seminal 1863 work *Sensations of Tone*, the scientist Hermann von Helmholtz gives the following information about the intensities of the harmonics for two different instruments. He used musical dynamic markings—from loudest to quietest, these are:

$$fff, ff, f, mf, mp, p, pp, ppp$$

You will have to decide how to convert these into amplitude levels between 0.00 and 1.00:

Instrument	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
X	f	ppp	f	p	mf	–	mf	pp
Y	f	mp	–	mf	–	p	–	p

Reproduce each of these two configurations in the PhET simulation using the sliders A_1—A_8, and listen to what they sound like. One of the instruments is a clarinet, and the other is an organ. Based on your sounds, think about which instrument might correspond to which spectrum from the table above. But as physicists, we can do better than deciding by ear!

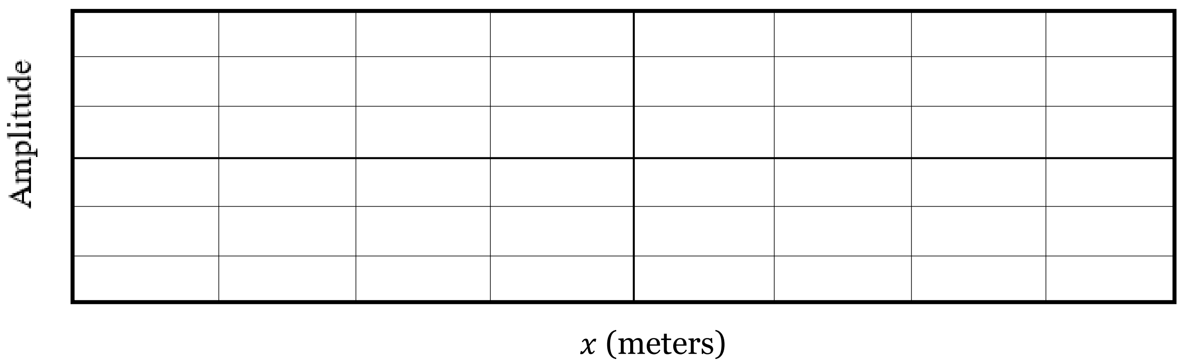
Download the two audio clips on Canvas accompanying this Homelab (organ.wav and clarinet.wav) and open them in Raven. Change the Focus slider to about 2000, and zoom in on the spectrogram view until the scale shows Hz instead of kHz. You can play these in Raven to hear what they sound like, but what we are interested in is the strength of the harmonics. In both cases, the fundamental is at 200 Hz, the second harmonic is at 400 Hz, the third harmonic is at 600 Hz, and so on. Since Instruments X and Y in the table above differ by whether the second harmonic is quiet and the third loud, or vice versa, determine from the spectrogram which instrument is which (and indicate this on your answer form). Why might your sound reproductions on the Fourier Series applet not be a perfect representation of the actual instruments?

Once you have your two plots for #1 and #2 and your answers for #3 (use the answer form on the next page), scan your homelab to a pdf file using a scanner or a smartphone app, and upload it to the Canvas assignment before it is due.

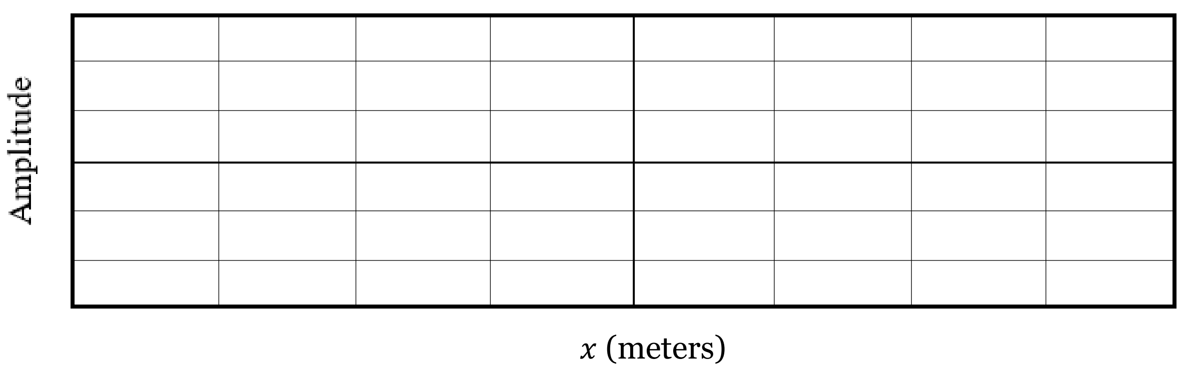
Answer Form

Name: ___________________________

1. A_1=1.00, A_4=1.00, A_8=0.50



2. A_{10}=1.00, A_{11}=1.00



3.

Instrument X is the _______________, and Instrument Y is the _______________.
Explanation:

Homelab #5

PHYS 1240: Sound and Music

Summer 2020

Instructions: Underlined portions indicate what you need to include in your submission to Canvas. Either type up your answers, or write them down and scan your work to a PDF. Be sure to show all your work (show *how* you get your answers), since physics isn't just about getting the right answers, but rather about the process of reasoning through problems and your ability to demonstrate that reasoning to others.

In this homelab, you will estimate the reverberation time of a room two different ways: (1) by recording an impulse noise and (2) by using Sabine's equation.

Part 1: Sabine's Equation

Step 1: To begin, choose a room for which you'd like to find the reverberation time. This could be any room in your house or beyond, but keep in mind that calculating T_{60} is easiest for rooms with simple dimensions and not too much clutter (since each extra item like a curtain or desk will mean an extra term for the total absorbing area).

Step 2: Measure the dimensions of your room. At the least, you'll need a length, width, and height, but depending on the room's shape, you might need to make more measurements in order to find the total volume. Record your measurements, making sure to include units. For Sabine's equation, you'll need to use SI units, so if your measurements are in feet, divide by 3.28 ft/m to convert to meters.

Step 3: According to Sabine's equation, the reverberation time of a room is approximately

$$T_{60} = (0.16\ \mathrm{s/m})\frac{V}{A_T},$$

where $V = \ell \times w \times h$ is the volume in m^3 and

$$A_T = a_1 A_1 + a_2 A_2 + a_3 A_3 + \ldots$$

is the total absorbing area in m^2, equal to the sum of each surface's area times that surface's absorption coefficient. For your chosen room, list all the important absorbing surfaces and find their absorption coefficients for 500 Hz and 2,000 Hz, using the table found in the textbook or the slides. Typically, you will need to include the four walls, the ceiling and floor, and any couches, beds, tables, chairs, and shelves. Be sure also to include your own body as an absorbing surface, since you'll be in the room when you make a measurement of T_{60}

for Part 2. In general, it's better to overestimate these absorbing areas than underestimate them, since you'll likely be leaving out some small surfaces from your calculation.

Step 4: Use Sabine's equation and all the information you have gathered to calculate the reverberation time for sounds at both 500 Hz and 2,000 Hz. Show your work and clearly label your two answers, making sure to include units.

Part 2: Recording Impulse Noise

Step 1: Now, you will directly measure T_{60} so you can compare it to your estimates from Part 1. To do so, we will use the impulse method, in which you create a loud, quick noise with an abrupt end and measure the decaying sound. First, set up Raven Lite to record in your chosen room (the same room as Part 1). Then, record yourself clapping loudly once, making sure to include the decaying sound until the room returns to ambient noise.

Step 2: Look at the spectrogram of your impulse noise. You should notice that the higher frequencies don't last as long as the lower frequencies, since faster oscillations lose energy and decay more quickly than slower oscillations. Now, zoom in to the 0–2 kHz range. We will be measuring T_{60} for 500 Hz and 2,000 Hz.

Step 3: On the spectrogram view, move your cursor to a point near the beginning of your decaying sound, at 500 Hz. At the bottom left of your screen, you should see 3 numbers: the time, the frequency, and the power. Once your cursor is as close to 500 Hz as you can get, read off the time in seconds and the power in dB, and keep track of those numbers. The "FS" next to the dB unit indicates that the decibels are "relative to full scale," which means that 0 dB FS corresponds to the loudest sound your microphone can handle, and quieter sounds are more negative decibels.

Step 4: Most likely, your sound won't have decayed a full 60 dB before reaching the ambient background noise level, so instead we'll measure T_{30} (the time to decay by 30 dB) and multiply by two. Take your decibel reading from the previous step and subtract 30, then find the corresponding point on the spectrogram that most closely matches that power for 500 Hz (if you start at your initial point and move your cursor right, you should notice the power decreasing linearly). Read off the new time from this point.

Step 5: Subtract your two times, then multiply by 2 to find the reverberation time T_{60} for 500 Hz. Then, do the same for 2,000 Hz and write down your T_{60}. How do these numbers compare to each other, and how do they compare to your estimates from Part 1? Think about why your calculations from Sabine's equation might differ from your measurements from a recorded impulse.

Scan your answers to a PDF, including all your intermediate work, and submit your homelab to Canvas.

Appendix C: Faculty Course Questionnaire (FCQ) Results for PHYS 1240: Sound and Music

Below are the FCQ results from the Fall 2023 iteration of PHYS 1240: Sound and Music. 134 students were enrolled in the course, and 35 students responded to the survey (this semester I did not take class time to allow students to complete the survey like I usually do). The qualitative results are presented first, followed by the quantitative results. For context, I've also included select qualitative comments from when I taught the same course in previous semesters, to demonstrate my growth as an instructor.

Student comments are included verbatim, separated by bullet points. Any clarifying remarks by me are shown in blue.

Summer 2019:

- The course was good, however the pace seemed to change after the midterm. It was harder to follow during this time. At times, the homework seemed to not match up with what was being learned in class. It seemed like we had to go to other sources to figure out the material.
- Make everyone sit in the front two rows. It encourages collaboration. [*Note for context*: This summer course had about two dozen students enrolled, but the lecture hall seated ~200, and students were allowed to sit anywhere.]
- the class could have been more engaging and more interactive with students. also 1/10 rating for the computer software used in the course [*Note for context*: The software mentioned here and in other later reviews is "Raven Lite," a sound spectrogram analysis software that the students needed for many assignments. After a few years I swapped it out for another software due to Raven's steep learning curve and escalating installation problems.]
- Informative and enjoyable course with all the demonstrations, but having the midterm and final being in different formats (one with short answer, one without) I believe is against testing standards at CU. It's pretty difficult to go into a final not knowing what exactly to expect (practice final exam, or not), especially during a condensed summer session. [*Note for context*: Rest assured that no CU testing standards were violated and each exam's format was clearly stated at the beginning of the term, but the student's comments are nonetheless valid and revealing.]

Summer 2020:

- I had a great time during this course despite it being online, I think the zoom norms are an extremely important aspect which most professors do not implement. It makes everything run much smoother in comparison to my other online courses. Thank you so much for the short summer session, I learned so much!
- Tyler was a great instructor. Whenever I had questions he would always respond quickly and was very helpful. Although some of the material was difficult conceptually, I felt like Tyler did a great job applying the material to real life and clarifying what was confusing. I think his teaching style was the best for this course.

Spring 2022:

- I loved the class topics and atmosphere! I really felt like I was truly learning the topics in real time and the pace was very manageable for myself and many others that I know!
- I really enjoyed doing the tutorials in class. They provided a fun way to apply our learning to practical problems and real world examples. I think students would benefit from them going forward. I also liked Raven as a software, although I may be in the minority with that statement. There is a slight learning curve but I found it fairly intuitive after using it for 2-3 home labs.
- Great professor. No problems with the course at all. It is very nice asking the students on what they want to learn and adjusting the course to that instead of just teaching out of a textbook.
- Tyler and TA's did a great job with this course. It was very interesting and not over complicated. If anything was to be improved, the homework format of printing off pages doesn't work for a lot of college students. I ended up just editing pdf's and it worked half-rate. Otherwise, I loved this course.
- More demonstrations!
- Made a difficult subject feel more approachable :)
- The only problem I saw was not being able to understand and use Raven Lite correctly until after the midterm. I think it would be very helpful to have a Raven workshop during class where the class learns how to analyze a sound. It would be the same sound for everyone and everyone would be following along with how to find the frequencies of the sound and learn how to use other tools in Raven that we would need to know for later in the semester. I enjoyed this class overall.

Spring 2023:

- I enjoyed Tyler's class. He understands that the people in this class (mostly) aren't physics majors. He gives us lots of opportunities to get a good grades. The tutorials are for completion grades which makes class way less stressful because it's okay if you mess up. I think that getting to do midterm corrections for credit was really helpful because I actually learned from my mistakes and was able to have this learning reflected in my grade. Tyler is really nice and I can tell that he really loves Physics. Sometimes he kinda stumbles over his words when explaining things or when someone asks a question. The one thing that would make his lectures better is more confidence because he knows what he is talking about. I also LOVE the demos he does. They are super engaging and you can tell that the whole class is not only paying attention but excited.
- This course was honestly run very well, and is organized in a very effective way. Splitting the class time between lecture and tutorial has been a nice setup, and the inclusion of instrument presentations and demos were spread out as nice extra bits of information. Overall, this course was a great way to finish off electives
- He has been honestly the best professor I'v ever had so far at CU Boulder. You can definitely see he really cares about what he is teaching and each and every student in his class. I was worried I would struggle in this class but he's been super understanding and helpful to caught back up. Thank you and you are so amazing!

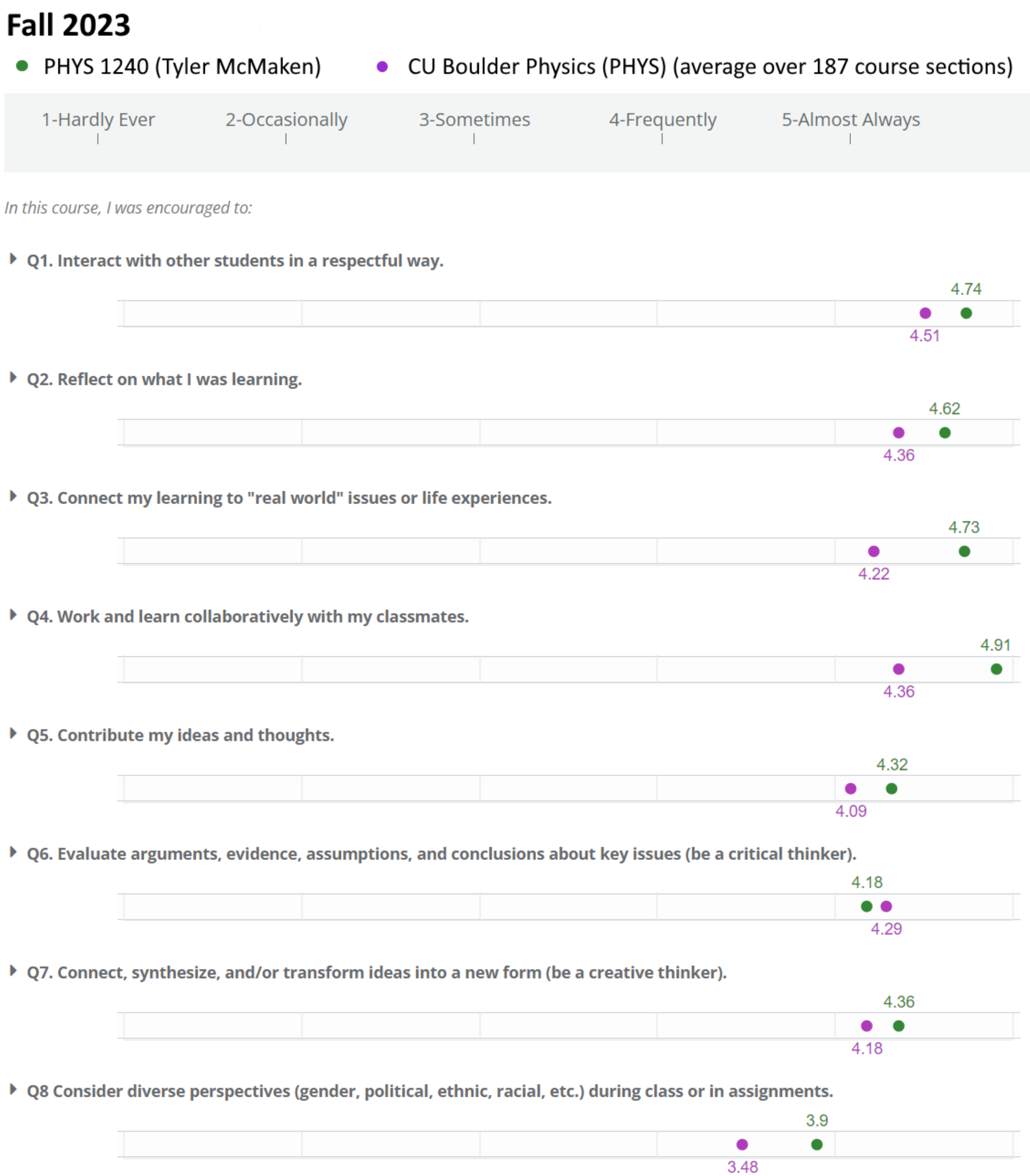
Fall 2023:

Qualitative results:

- I enjoyed how much this class was group oriented and on our own time to succeed. I think by also having demonstrations in class the connections between what we were learning and the real world were made clear.
- Tyler McMaken was one of the nicest and most understanding professors I have had at CU. He is always there to help and answer questions and sets his students up to succeed. It is challenging material, but made easier through his teaching style.
- I enjoy the demonstrations we'd get to see.
- This class was one of my favorites. I enjoyed the lecture tutorial demonstrations. Without them, the class could get very boring. I liked the attendance policy a lot and took advantage of it at times. Homelabs were graded fairly, as was the midterm. This is the perfect example of how a 1000 level class should be taught in my opinion.
- You are amazing!! Your classes are so fun, I love how you almost always do an experiment during class. Posting your slides is also very helpful. Great job!!
- I thought this course was very well taught and well paced.
- I enjoyed having homelabs to reinforce topics we learned in class.
- The demonstrations of physical phenomena were the best part of the class for me. I felt like I understood the concepts much better when it was visually present. The tutorials are my least favorite part of the course, as I would rather have those assignments as homework, to then use the extra class time to go more in-depth into the concepts at hand.
- This professor is amazing. You can tell he's energetic and passionate towards what he's teaching and he is approachable. I almost dropped the class the first week due to the substitute teacher not being super comprehensible but I am very glad I stayed.
- I really loved this course and thought Prof. McMaken did a great job teaching it! The subject material was super interesting and it's clear that he is very passionate about the subject and really wants his students to succeed. I appreciated how low-stress the class was because it felt like the perfect balance between accountability and flexibility that a non-major physics class should have. I also feel like the low-pressure environment placed the emphasis on learning because of interest rather than just trying to get good grades, which is kind of a rare thing in higher education. Prof. McMaken is knowledgable and very understanding when his students don't understand a concept. Overall I just think this was a really fun class which I would definitely recommend it to others!!
- I really enjoyed this class. First going in I was intimidated by the fact that this is a physics class. However, the instructor explained everything well for anyone with any type of math or physics background could understand. Office hours were a huge help and I always left feeling like I understood the material better. I liked the class structure, half lecture half tutorial work. The course load was perfect and related to the class.
- Super nice guy, good workload
- I really enjoyed this class as a person who struggles with physics and math. We did have an exam but he allowed corrections and to provide different ways of getting a good grade other than just exams.
- Overall solid class. The content was presented in a mostly enjoyable way, and the assignments helped me learn the material. Tyler is very helpful and tries to help as best he can.
- THIS MAN IS AN AMAZING TEACHER, I absolutely HATE physics and somehow he never fails to make this course fun and interactive. Give him a raise.

- Tyler always explained things in a simple way and everything he said would always make sense. He was also such a kind instructor and would always be so respectful to all students. He was always around when we needed that extra help.
- Such a great teacher, made learning fun and helped me actually learn a lot.
- Thank you for this semester. I greatly appreciate your prioritization on the materials of this course and the information that we learned, rather than grading and tests. I think that if you were to add clickers as another way to grade participation, a larger majority of the class would show up. I also really like how you handled homework. I think that the homelabs were a good application of course information, and I was thankful that they were every other week rather than weekly.
- The slides were effective by going slow through them and taking time to explain everything. The tutorials weren't the most helpful but sometimes they were
- Professor McMcMaken is an AMAZING teacher overall! He's super kind and respectful to everyone and it is very evident that he's incredibly passionate and knowledgable about what he's teaching which kept me super engaged throughout the semester. It was also very clear that he really wanted to help all of his students thrive in the class and he did that very effectively. The demonstrations were always so cool and fun and such an effective way of helping us understand the class material. He also really creating a sense of community amongst the students by ecouraging us to work together with a group throughout every class, which also helped keep me engaged and excited about class and helped me perform well. Thank you so much professor McMaken!! Keep it up!!
- Almost wished we delved a little deeper into psychoacoustics and other acoustic related topics, but overall my most enjoyable class! Had a lot of fun!
- Great job teach you have a really fun and interesting class.
- The demos during the classes were very helpful to understand how physics actually works in the real world.

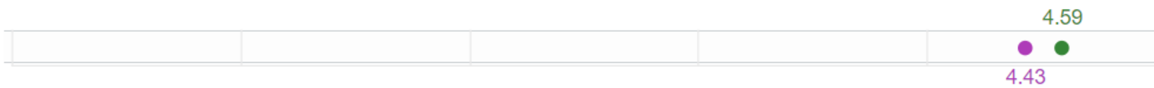
Quantitative Results:



In this course, the instructor:

Q9. Demonstrated respect for diverse students and diverse points of view.

Q10. Challenged me to develop my own knowledge, comprehension, and conceptual understanding.



Q11. Gave projects, tests, or assignments that required original or creative thinking.

Q12. Provided opportunities for students to ask questions and initiate discussion.

Q13. Provided feedback on my work that helped me improve my performance.

Q14. Explained the grading criteria for assignments.

Q15. Was available to answer questions or provide assistance when needed.

Q16. Effectively used available technology to enhance learning.

Appendix D: Epistemological Beliefs Assessment for Physical Science (EBAPS) Results for PHYS 1230: Light and Color

The Epistemological Beliefs Assessment for Physical Sciences (EBAPS) is a survey designed to probe students' beliefs and attitudes about physics: is success in science based on fixed natural ability? To what extent does physics describe the real world? How is scientific knowledge structured, and can it evolve over time? I instituted this survey twice during the Spring 2021 semester of teaching "PHYS 1230: Light and Color" in order to understand how well my students learned this hidden curriculum.

Unfortunately, I was not able to institute a pre-semester survey and only ended up giving it to the students in the middle of the semester and again at the end. The results were not statistically significant in any regard, but there was a slight trend toward more positive epistemologies as a result of my active pedagogical practices.

Content & Scoring:

EBAPS relies on a non-linear scoring system. Each question is given a unique grading rubric, with the most expert-like option given a score of 4 (assuming there is a single expert-like answer) and the least expert-like option given a score of 0. The scoring rubric along with the survey itself is publicly available online (Elby, 2001).

Additionally, EBAPS is scored along five different axes: structure of knowledge (how facts-based physics is and how cohesive as a field it is), nature of learning (how students best learn physics), real-life applicability (how important physics is in students' everyday experiences), evolving knowledge (how physicists come up with theories and change their understanding of the world), and source of ability to learn (metacognitive skills and fixed vs. growth mindsets). I chose to focus my attention on the third axis (real-life applicability), since I was most interested in showing the non-major students how the field could apply to their everyday experiences (and the nature of the topics covered in the course lent itself to this goal).

Results:

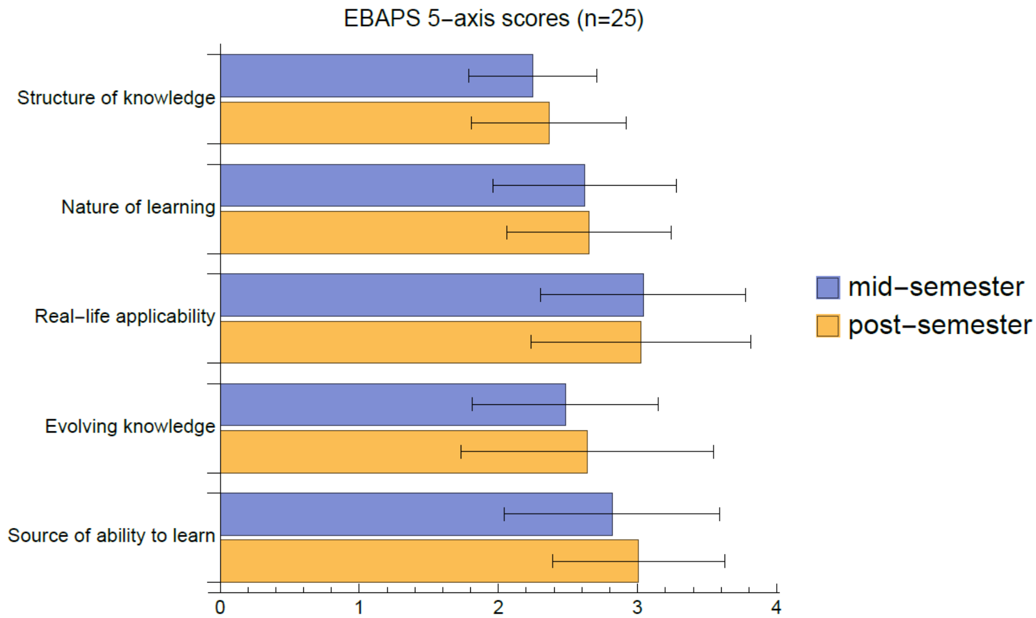
The changes in the students' EBAPS scores from the middle of the semester to the end of the semester for each of the five axes are shown in Figure D1. The key result that I initially sought to uncover is that there was no statistically significant gain or loss in how expert-like the students' epistemologies changed throughout the second half of the semester. There does appear to be a slight positive trend when looking at the average scores along each axis, but the small number of students involved precludes any conclusions about statistically significant changes.

From the data in Figure D1, it can be seen that the students scored the highest along the third axis, real-life applicability. This was the axis that I was most intentional about addressing in the course, so I am pleased to see that the students were able to develop positive epistemologies in this regard. It is likely that much of that development came in the first half of the semester, which raises further questions about how quickly students' epistemologies generally change throughout the course of a single semester.

The average EBAPS mid- and post-semester scores along two different dimensions (class and gender) are shown in Figure D2. The dashed line in these plots (and in the lower panel of Figure D1) is not a trend line; rather, it divides the region of positive change in epistemological attitudes from the region of negative change. No clear trends can be seen in either plot; it seems that the classroom was an equitable environment for students of all ages and genders.

The final plot shown, Figure D3, gives the total amount of time it took for each student to complete the assessment (data readily available from the Canvas quizzing platform). The data have been divided into the mid-semester and post-semester assessment times, since each iteration was administered in a specific context and results should really only be compared across the same iteration of the assessment. The recommended time to complete the 30 EBAPS questions is 15 to 22 minutes, corresponding to an average recommended time per question of 30 to 44 seconds (shown by the gray vertical lines in the plot). In contrast, most students took less than the recommended amount of time. In fact, five outliers on the left of this plot had to be excluded from the data set in the prior plots because those students took less than 2 minutes to complete the entire assessment, and from their responses it was clear that they had chosen random answers for a majority of the quiz. The only safeguard against this was the final question of the assessment, "True or False: I acknowledge that I have complete this assessment on my own and that all responses reflect my own beliefs." In the future, I would like to add a more detailed final question or set of questions similar to what was done in Cornell's PLIC survey (and plenty of other similar surveys) to gauge explicitly to what degree the students put effort into their responses (Holmes, 2015).

In the end, I hope to continue implementing most if not all of the pedagogical techniques mentioned here for my future classes. It was a great struggle trying to engage students over Zoom throughout the course of the semester, and I can only imagine how much worse it would have been for me and for the students if I had stuck with a traditional lecture format throughout the semester. Many elements of this course's design will remain unique to its hybrid virtual environment. Nonetheless, can come away from this study not only with a greater knowledge of how to teach in a hybrid virtual environment, but also with a brighter hope of creating an even more positive educational environment once these methods can be returned to their original in-person forms.



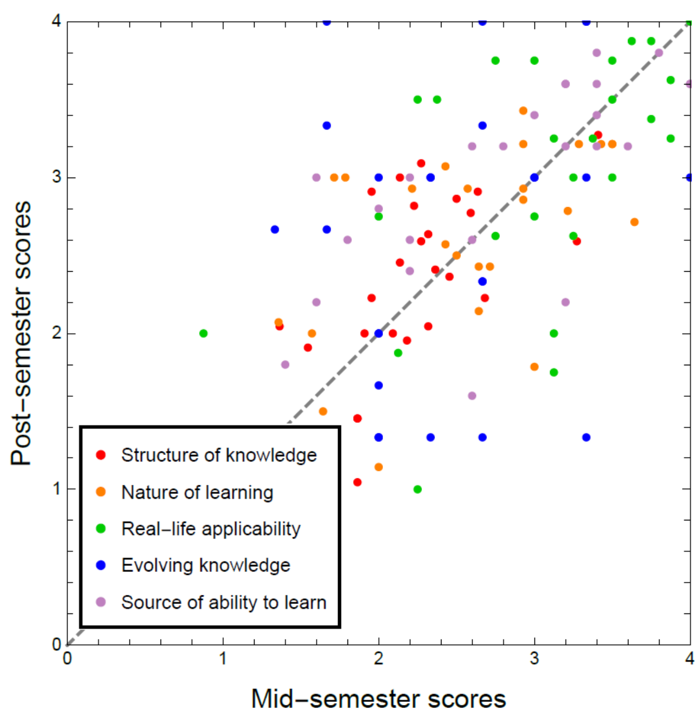


Figure D1: Mid- and post-semester EBAPS scores divided by five axes. Top: average scores with standard deviations. Bottom: individual scores showing the distribution of the data.

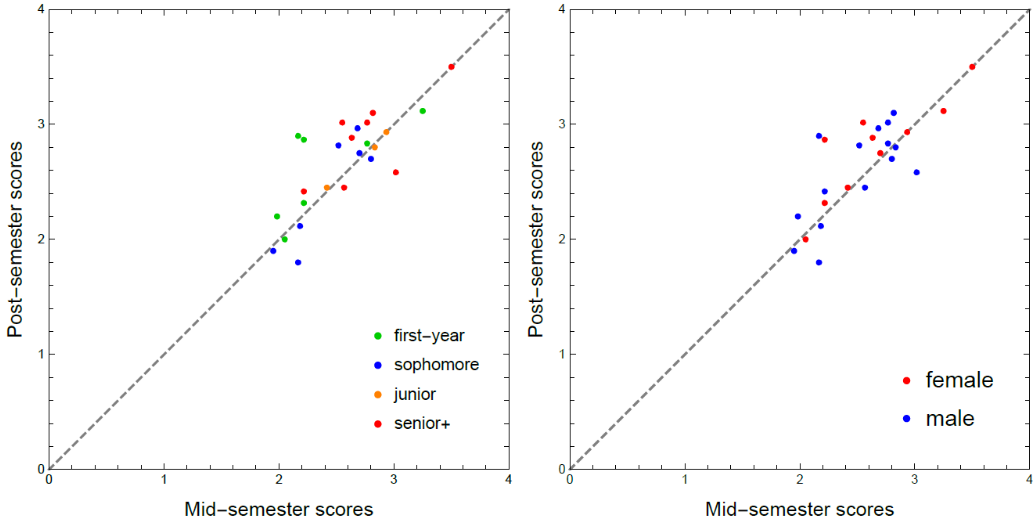


Figure D2: Average mid- and post-semester EBAPS scores displayed for different student's year in college (left) and gender (right).

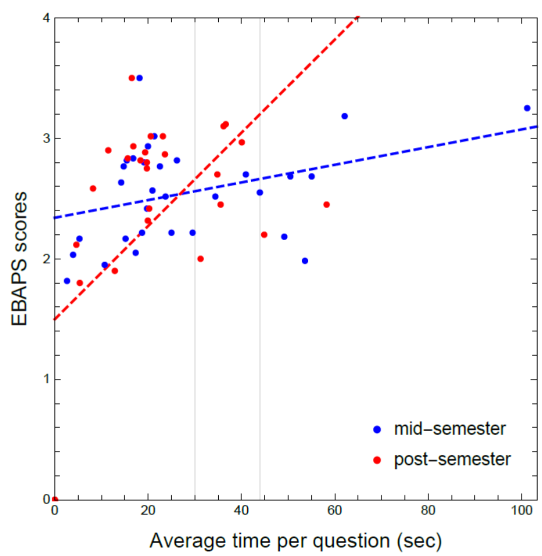


Figure D3: Average EBAPS scores for each student as a function of the time it took to complete the assessment. Lines of best fit for the mid- and post-semester iterations of the assessment are shown in dashed blue and red, respectively. The recommended minimum and maximum times to complete the assessment are shown with the gray vertical lines.

Appendix E: Syllabus for CU-Prime Course

PHYS 1400 *Fundamentals of Scientific Inquiry*

Fall 2021

1 Sections, Instructors, & Office Hours

Section	Days/Time	Room	Instructors	E-mails
801	TTh 5:30-6:45 p.m.	DUAN F1117	Tyler McMaken Hassan Hassan	tyler.mcmaken@colorado.edu hassan.hassan@colorado.edu
802	TTh 5:30-6:45 p.m.	DUAN G1B31	Hope Whitelock Federico Ameijenda	hope.whitelock@colorado.edu federico.ameijenda@colorado.edu

Office hours are as follows:

Hope: TTh 5:00-5:30 pm, DUAN G1B31
Federico: TTh 6:45-7:15 pm, DUAN G1B31
Tyler: TTh 6:45-7:15 pm, DUAN F1117
Hassan: TTh 5:00-5:30 pm, DUAN F1117

Instructors will hold office hours in their respective classrooms. You may also contact your instructors via e-mail (use the addresses listed above) to set up meeting times outside of the times listed. For general questions for any of the instructors, you can always contact the class email, phys1400@colorado.edu

2 Course goals

The goal of the course is to introduce students to what it means to be a scientist by developing creative problem solving skills, improving communication and collaboration, and introducing students to cutting-edge research (without the confusing jargon).

Over the course of the semester we will:

- **Practice developing scientific models that give insight into the way things work.** In building models, we will try to condense complicated situations into the simplest useful picture. We will do this by identifying questions, determining the important variables and parameters, collecting and analyzing data, and drawing conclusions based on that data.
- **Better understand how we think and learn.** Science is about finding out new things, so it helps to first find out how we learn. We will see that academic ability is like a muscle we can strengthen it by using it. By implementing strategies developed through years of education research, we can improve ourselves both as students and scientists.
- **Reflect and refine.** From Galileo to Newton to Curie to Einstein and beyond, scientists are repeatedly refining their (and our) understanding of reality. The models that we learn in our science classes are not the end of the story. You will find that as you progress in your coursework, you will revisit the same models again and again, digging deeper into the complexity of the model each time. Our work as scientists is to find the places where models can be extended, tweaked, or even completely overhauled. Similarly, throughout our lives we adjust our ideas about who we are, what we value, and how we learn. We benefit from self-reflection both as scientists and students.
- **Collaborate effectively in groups.** Modern science is so complex that scientists rarely work alone. The ability to work and communicate with others is therefore crucial.

3 Course format

This course consists of two 75-minute sessions each week. Most work in class will be conducted in small groups, and information will be shared between groups through whole-class discussions. In the first half of the semester, we will practice the process of developing a scientific model and explore how we learn. The second half of the semester will consist of group projects in the form of longer experiments run by students. Interspersed throughout the entirety of the semester, there will be the CU-Prime talks from undergraduates, graduate students, or postdocs. These talks are designed for undergraduate students, and the goal is to give students a glimpse into physics research being done at CU.

3.1 Expectations

This course is a letter-grade course, based on

- attending all class sessions, including CU-Prime talks,
- actively participating in class and being an engaging member of your team,
- completing small reflection assignments,
- completing the final group project.

Please inform your instructors in a timely manner if circumstances prevent you from meeting these expectations. Alternative activities can be assigned on a case-by-case basis. You will be required to be punctual and organized in this course. Please arrive on time for class, organize and keep track of any handouts and assignments, and do not pack up and leave before class time is over. In general, weekly assignments will be posted on Tuesdays and will be submitted on Canvas by the beginning of the next class of the same week.

3.2 CU-Prime Talks

The CU-Prime Talks will take place in the Commons Room (DUAN F1117, Gamow Tower) every other Tuesday. During these talks, CU graduate students talk about their research, career path, and day-to-day work. This will give you an insight in the day-to-day life of a researcher. You will never be required to retain the specific science content of each talk, though when applicable, CU-Prime speakers will also tie in their work to what you are learning in PHYS 1400.

3.3 Group Projects

The group projects in the second half of the semester are actual scientific studies of physical phenomena. Starting from scratch, with the help of a graduate or upper-division undergraduate advisor, each group (3-4 students) will write a short proposal on their experiment. Then, using the proposal, each group will devise and conduct an experiment in the subsequent weeks. At the end of the semester, each group will present their findings in a public poster session.

4 Course Calendar

Week	Date	Tuesday	Date	Thursday
1	8/24	Introduction	8/26	Models: Gravity
2	8/31	Models: Light Rays	9/02	Models: Light Bending
3	9/07	First CU-Prime Talk	9/09	Diversity Workshop
4	9/14	Models: Moon Formation	9/16	Group Match-up
5	9/21	CU-Prime Talk	9/23	Begin Group Projects
6	9/28	Failure in Science	9/30	Group Projects
7	10/05	Metacognition	10/07	Group Projects
8	10/12	CU-Prime Talk	10/14	Group Projects
9	10/19	Process of Science	10/21	Group Projects
10	10/26	CU-Prime Talk	10/28	Group Projects
11	11/02	Research Q&A	11/04	Group Projects
12	11/09	CU-Prime Talk	11/11	Group Projects
13	11/16	Lab Tours	11/18	Group Projects
–	11/23	Fall Break - no class	11/25	Fall Break - no class
14	11/30	CU-Prime Talk	12/02	Practice Presentation
15	12/07	Poster Session	12/09	Semester Wrap-up

5 Grading Breakdown

Though we do not intend for grades to be the main focus of this course, we use the following grade breakdown to assign individual grades as per University standards. All grades will be updated and posted on the course's Canvas site as the semester progresses. Final letter grades will be assigned using a standard grading scheme. For more information on individual items, see Expectations (3.1) above.

Item	Percentage of grade
Attendance	10%
Participation	40%
Reflection assignments	20%
Final group project	30%

6 Course Credit

PHYS 1400 is a one credit course. Although it is a valuable experience which will help you develop as a scientist, it cannot count for credit toward Physics major requirements in the college of Arts & Sciences, due to uncontrollable department standards. However, the course may count towards your graduation requirements as an elective credit, depending on your major. For more information on how credit for this course fits within your department's standards, please check with your academic adviser.

7 Online Resources & Emails

The Canvas site (link below) will be used to keep track of grades, for turning in reflection assignments due on Thursdays, and to access relevant information, including the syllabus, instructor information, and group project details. Any questions you may have throughout the course can be brought to the instructor team through the instructor team email address listed below. In addition, information about CU-Prime as a whole can be obtained on their website or through email.

Canvas site:	canvas.colorado.edu/courses/76610
Instructor team email:	phys1400@colorado.edu
CU-Prime Website:	cuprime.org
CU-Prime E-mail:	cu-prime@colorado.edu

8 Photo use consent

Throughout the semester, photos of various class activities will be taken. Some photos may have individual students as the focus, others may be photos of large groups/audiences in which your face is visible. We ask for your consent to use these photos in flyers, presentations, on our website, and through social media for promotional purposes. Your name and personal information would not be published in any way without your permission and knowledge.

If you do not agree to let us use photos we take of you, please let us know as soon as possible. Furthermore, you can always revoke the right to use your photos in the future, but not retroactively.

9 Late policy:

If, due to unavoidable circumstances, you are unable to complete an assignment by the set due date, please reach out to the instruction team to request an extension. With the exception of the final group project poster, we are always willing to accept late assignments. Full credit can still be received for assignments turned in late if extenuating circumstances are brought to instruction team **before an assignment's due date**, but if the instruction team does not hear from a student by the time an assignment is due, we reserve the right to apply a 25% grade reduction to any late assignment.

10 Special circumstances

10.1 Incompletes:

Rules of the University require that grades of incomplete (I) may be assigned only if "*for reasons beyond the student's control, the student is unable to complete the course requirements.*" "I" requests must be made in person to the instruction team.

10.2 Accommodation for Disabilities:

If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to the instruction team in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website. Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

10.3 Classroom Behavior:

Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. For more information, see the policies on classroom behavior and the Student Code of Conduct.

10.4 Preferred Student Names and Pronouns

CU Boulder recognizes that students' legal information doesn't always align with how they identify. Students may update their preferred names and pronouns via the student portal; those preferred names and pronouns are listed on instructors' class rosters. In the absence of such updates, the name that appears on the class roster is the student's legal name.

10.5 Honor Code:

All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code academic integrity policy. Violations of the Honor Code may include, but are not limited to: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found on the Honor Code website.

10.6 Sexual Misconduct, Discrimination, Harassment and/or Related Retaliation:

The University of Colorado Boulder (CU Boulder) is committed to fostering an inclusive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct (harassment, exploitation, and assault), intimate partner violence (dating or domestic violence), stalking, or protected-class discrimination or harassment by or against members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or email cureport@colorado.edu. Information about OIEC, university policies, reporting options, and the campus resources can be found on the OIEC website.

Please know that faculty and graduate instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, dating and domestic violence, stalking, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about their rights, support resources, and reporting options.

10.7 Religious Holidays:

Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments or required attendance. In this class, please approach your instruction team to discuss arrangements for religious holidays. See the campus policy regarding religious observances for full details.

10.8 Requirements for COVID-19

As a matter of public health and safety due to the pandemic, all members of the CU Boulder community and all visitors to campus must follow university, department and building requirements and all public health orders in place to reduce the risk of spreading infectious disease. Students who fail to adhere to these requirements will be asked to leave class, and students who do not leave class when asked or who refuse to comply with these requirements will be referred to Student Conduct and Conflict Resolution. For more information, see the policy on classroom behavior and the Student Code of

Conduct. If you require accommodation because a disability prevents you from fulfilling these safety measures, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus.

As of Aug. 13, 2021, CU Boulder has returned to requiring masks in classrooms and laboratories regardless of vaccination status. This requirement is a temporary precaution during the delta surge to supplement CU Boulder's COVID-19 vaccine requirement. Exemptions include individuals who cannot medically tolerate a face covering, as well as those who are hearing-impaired or otherwise disabled or who are communicating with someone who is hearing-impaired or otherwise disabled and where the ability to see the mouth is essential to communication. If you qualify for a mask-related accommodation, please follow the steps in the "Accommodation for Disabilities" statement on this syllabus. In addition, vaccinated instructional faculty who are engaged in an indoor instructional activity and are separated by at least 6 feet from the nearest person are exempt from wearing masks if they so choose.

Students who have tested positive for COVID-19, have symptoms of COVID-19, or have had close contact with someone who has tested positive for or had symptoms of COVID-19 must stay home. In this class, if you are sick or quarantined, notify the instructors on Canvas or by email at your earliest convenience, and we will make every effort to accommodate. Note that you are not required to state the nature of your illness or to provide a "doctor's note," nor will the instructors ever share information about your health status with the rest of the class.

For the most up-to-date syllabus statements related to special circumstances and campus policies, see this document.

VII. WORKS CITED

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